Three-Dimensional Implant Position and Orientation After Total Knee Replacement Performed with Patient-Specific Instrumentation Systems

Francesco Cenni,[1] Antonio Timoncini,[2] Andrea Ensini,[2] Silvia Tamarri,[1] Claudio Belvedere,[1] Valentina D'Angeli,[1] Sandro Giannini,[1,2] Alberto Leardini[1]

[1]Movement Analysis Laboratory-Clinical and Functional Evaluation of Prostheses, Istituto Ortopedico Rizzoli, Bologna, Italy, [2]Department of Orthopaedic Surgery, Istituto Ortopedico Rizzoli, Bologna, Italy

Received 15 February 2013; accepted 4 October 2013

Published online 30 October 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/jor.22513

ABSTRACT: Patient-specific instrumentation systems are entering into clinical practice in total knee replacement, but validation tests have yet to determine the accuracy of replicating computer-based plans during surgery. We performed a fluoroscopic analysis to assess the final implant location with respect to the corresponding preoperative plan. Forty-four patients were analyzed after using a patient-specific system based on CT and MRI. Computer aided design implant models and models of the femur and tibia bone portions, as for the preoperative plans, were provided by the manufacturers. Two orthogonal fluoroscopic images of each knee were taken after surgery for pseudo-biplane imaging; 3D component locations with respect to the corresponding bones were estimated by a shape-matching technique. Assuming that the corresponding values at the preoperative plan were equal to zero, discrepancies were taken as an indication of accuracy for the systems. A repeatability test revealed that the technique was reliable within 1 mm and 1°. The maximum discrepancies for all the patients for the femoral component were 5.9 mm in a proximo-distal direction and 4.2° in flexion. Good matching was found between final implantations and preoperative plans with mean discrepancies smaller than 3.1 mm and 1.9°.
 J Orthop Res 32:331–337, 2014.

Keywords: total knee replacement; patient-specific instrumentation; three-dimensional fluoroscopy analysis; prosthesis component positioning

Computer-assisted techniques in total knee replacement (TKR) have resulted in more accurate alignments than those after conventional implantation,[1–5] though misalignments of the prosthetic components and the mechanical axis have been still reported.[6] More recently, patient-specific instrumentation (PSI) has been proposed with the aim of positioning prosthetic components according to the patient lower-limb and bone alignments. Computer models of the distal femur and proximal tibia are defined from scan acquisitions using computer tomography (CT) or magnetic resonance imaging (MRI). Based on these models, presurgical TKR planning is performed and offered for the examination and adjustment of the surgeon via web-based interfaces. Corresponding patient-matched cutting guides are then manufactured and delivered to the hospital.

Cheaper and faster surgical procedures with PSI have been claimed, but their relevant accuracy must be shown in terms of final TKR alignment. Radiographic measurements have been taken to assess the lower-limb mechanical axis[7,8] but these are limited to 2D only in the sagittal and coronal planes and can be severely affected by manual errors in landmarks identification.[9,10] Access to transverse plane alignments is allowed by CT scans,[6,11,12] but this exposes the patient to intensive radiation, time consuming acquisitions, and critical analytical procedures.

No long-term outcomes are available for this PSI, and initial studies report contrasting results.[13–18] Better overall alignments in the coronal plane have been claimed,[14,16] but this is questioned elsewhere[13] and limited by radiographic measurements. Because the surgical plan is approved by the surgeon based on careful analysis of 3D models, the main issue for these innovative procedures is whether the final component alignments are in accordance with the computer-based preoperative plan. For this purpose, double plane fluoroscopy together with standard shape-matching procedures[19] can provide accurate and less invasive 3D measurements of the component alignment. Final 3D component-to-bone position and orientation (hereinafter altogether referred to as pose) can also be provided if the models of bone preparation are available.

We assessed the 3D accuracy of two commercially available PSI systems, comparing relative component-to-bone positions and orientations at the replaced knee soon after surgery with the corresponding ones in the preoperative plan, assumed to be zero. Two orthogonal fluoroscopic images and the standard shape-matching technique were used.

MATERIALS AND METHODS

In the present study, 44 patients affected by primary symptomatic knee osteoarthritis and treated surgically at the authors' institute for TKR with PSI procedures between January 2011 and April 2012 were analyzed. These patients provided informed consent upon approval by the local Ethics Committee. Twenty-three were treated by the MyKnee® system (group A) and implanted with the GMK® (Medacta-International, Castel San Pietro, CH), and 21 by the Visionaire® system (group B) and implanted with the Journey® (Smith&Nephew, London, UK). In one knee in group A, a stemmed tibial component was implanted independently of the procedure because of evidence of bone defects. The cutting guides were made according to the manufacturer's own standard PSI procedures: from CT scan acquisitions of the hip, knee, and ankle joints in group A, and MRI scan

Conflicts of interest: None.

Correspondence to: Claudio Belvedere (T: +39-051-6366570; F: +39-051-6366561; E-mail: belvedere@ior.it)

acquisitions of the knee joint together with an overall X-ray picture of the lower limb in group B. At the femur, full 3D bone preparation was performed by the cutting guides, which are affixed to osteophytes in group A, or to articular surfaces in group B. At the tibia, full 3D bone preparation was performed by the cutting guides only in group B; in group A, only the orientations in the coronal and sagittal planes and the proximo-distal position were performed automatically, and the rest visually checked and manually performed. However, in both systems the final 3D target for component alignment was defined, according to manufacturer and surgeon recommendations via web-based preoperative planning software. This implied setting a neutral mechanical axis alignment for the lower limb. The implants used in all cases were cemented, posterior-stabilized TKRs with resurfaced patellae, and all were implanted by the same surgeon.

A few days after surgery, two single orthogonal X-ray images were collected for each patient in static supine posture with the replaced knee fully extended, using a standard fluoroscope (Helios DRF; CAT Medical System, Rome, Italy): one in the lateral projection (sagittal plane view) and one in the AP projection (coronal plane view). During each of these imaging sessions, two additional images were collected: one with a metal ruler of known length and one with a 3D Plexiglas cage with fiducial beads in known positions, which were necessary to calculate the pixel-to-mm conversion and localize the camera focus, respectively.[20] CAD models for the femoral and tibial components and relevant reference frames, whose origins were located in the center of the internal femoral box and the tibial baseplate, were provided by the manufacturer and the relevant bones with osteotomies were obtained for distal femur and proximal tibia (Fig. 1) from the patient-specific preoperative plans.

Absolute 3D position and orientation of the components and corresponding bone models were measured on each image. The estimation was performed using existing software (KneeTrack®, University of Florida) based on an established technique,[19] in which the best superimposition between the planar projection of the 3D CAD model and the corresponding silhouette on the fluoroscopic image is sought by manual matching (Fig. 1). Previous validation work showed that, in a single image, this technique had an accuracy of more than 1.0° and 0.5 mm for in-plane position and orientation, respectively.[19,21] This matching was performed on the sagittal plane image first, in which an initial estimation of the 3D pose was obtained. This pose was then used as the first guess of a similar analysis in the coronal plane image for the final values. Relative component-to-bone pose was defined, according to a standard convention,[22] in terms of antero(+)/posterior (A/P), medio(+)/lateral(−) (M/L), and proximal(+)/distal(−) (P/D) positions, and valgus(+)/varus(−), flexion(+)/extension(−), and internal(+)/external(−) orientations, respectively, in the coronal, sagittal, and transverse anatomical planes. In both segments, the discrepancies were of the component with respect to the bone, in a way a knee with anterior tibial slope is represented by flexion of the component. These values, obtained with the final prosthesis implanted, were compared to the corresponding ones in the preoperative plan for both the femur and tibia. In particular, the sum of the discrepancies on the coronal plane of the femur and tibia was assumed representative for the final mechanical axis discrepancy, possibly differing from the planned 0°. Discrepancies larger >3° and 3 mm were considered outliers.[23]

To test the accuracy of the present technique, a sample of one of these two TKR designs was fixed to a Plexiglass workbench in a known relative position. Three couples of

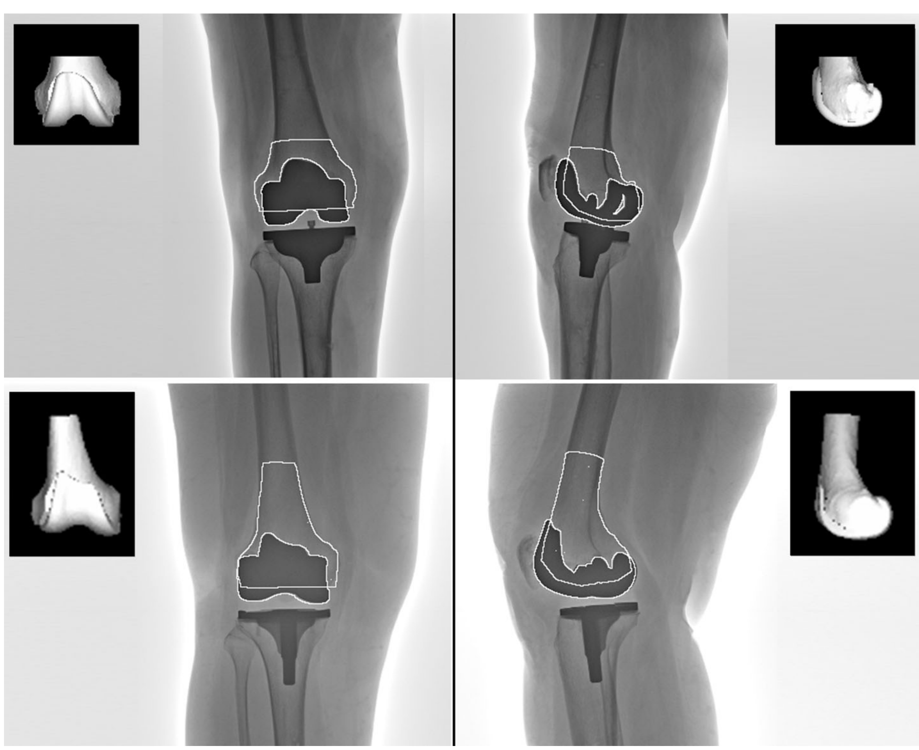

Figure 1. Coronal (left) and sagittal (right) fluoroscopic images of replaced knees from a representative patient in group A (top) and one in group B (bottom), superimposed with the corresponding planar projections of the 3D CAD models, both of the prepared bone and of the femoral component, as provided by the software adopted for 3D pose estimation. Relevant snapshots of the component-plus-bone models are also shown.

images from the two planes were taken similarly to those obtained for the patients, and the relevant shape matching procedure was performed five times, 1 day apart, by three operators with various degrees of experience with this procedure.

To test the repeatability of this technique for relative pose estimation on images from TKR patients, the same image pairs were analyzed in three sessions by the same operator $\geq$1 week apart; for each of the six discrepancy variables (three positions, three orientations), the standard deviation and the maximum error over the three repetitions were calculated. This repeatability test was performed on four representative randomly chosen patients, two from each group.

Statistical analysis was performed using the *t*-test for paired samples between different variables within the same PSI system and the unpaired samples for the same variable between the two systems. For each test, $p < 0.05$ was considered significant. All calculations were made using Matlab software (The Mathworks Inc., Natick, MA).

RESULTS

For the accuracy test, the mean error was <0.2° in all planes and <0.5 mm along all axes. For the intra-operator repeatability tests (Table 1), the means of the standard deviations over the three repetitions were found in orientations all <0.9°, apart from internal/external orientation at the tibia (1.2°); the same means were found in positions all <0.8 mm, apart from the A/P position at the femur (1.6 mm).

For both PSI systems and for both the femur and tibia, the mean discrepancy in absolute values in the three position directions was <3.1 mm, although in single cases this was as large as nearly 6 mm in the M/L direction (Table 2). Better results were found at the tibia, in particular in group B, the best being A/P and M/L positions (1.1 mm on average). The separate occurrences in the two directions somehow revealed a bias in proximal and medial orientation at the femur and in the posterior position at the tibia for group A. For the orientation, the mean absolute discrepancies were all within 1.9° for both systems (Fig. 2), the worst being the femoral orientation in the sagittal plane for group A. The minimum absolute discrepancy was in the tibial coronal plane, that is, 1.0° in group A. The largest number of outliers occurred in the sagittal plane at the femur in group A and in the tibia in group B. These orientation values, taken with their own original directions, showed dispersed results (Fig. 3), the largest discrepancy over all patients being 4.2° flexion for the femoral component in group A. The largest bias was found in the sagittal plane of group A, for the femur and tibia, 20 and 17 occurrences of discrepancy in flexion, respectively (Table 3).

When comparing the two PSI systems, some significant differences for the discrepancy values were observed. Particularly, for the positions, the A/P and M/L at the tibia in group A were larger than those of group B. The present results also revealed significantly more varus and a more flexed femoral component in group A than in group B (Fig. 3). The mechanical axis was $-0.9 \pm 2.3°$ and $0.7 \pm 2.4°$ for group A and group B, respectively, with three outliers in each group.

DISCUSSION

A novel overall technological procedure has been introduced into computer-assisted TKR. From original patient-specific imaging, custom-fit bone cut guides are manufactured by knee implant manufacturers with the objective of eliminating the traditional instrumentation set, which has to be taken sterilized into the operating theater, rather than simply taking the patient-matched guides and the corresponding implant. The potential sources of error for this complex procedure are numerous, but the main original interest of the clinical and biomechanical communities is the expected correspondence between the careful computer-based surgical plan and the final result, in terms of accuracy in relative position and orientation between the prosthesis components and the prepared bone, which has been assessed in the present study. This is also justified by a recent claim[18] that intra-operative adjustments in PSI systems are frequently necessary by the surgeon. Our results were obtained in 3D by an original technique, for both the femur and the tibia, using only two standard medical images with low radiation, and from two different PSI systems.

The present calculations have potential sources of inaccuracy. The main one is the original spatial matching of the 3D models of the prepared bones, the distal femur, and proximal tibia. The diaphyseal part of the bone is almost cylindrical, and therefore the axial rotation is hard to estimate, whereas the epiphyseal part is obscured by the implant (Fig. 1). However, the remaining references for these models allowed repeatable final pose estimation (Table 1). The global 3D pose is calculated by a semiautomatic procedure performed on two different images, where the operator's

Table 1. Intra-Operator Repeatability

	Femur			Tibia		
	Valgus/varus	*Flex/ext*	*Intra/extra*	*Valgus/varus*	*Flex/ext*	*Intra/extra*
Orientation [deg]	0.8 [1.1 ÷ 1.7]	0.9 [1.2 ÷ 2.0]	0.8 [0.3 ÷ 2.7]	0.3 [0.1 ÷ 1.1]	0.5 [0.2 ÷ 1.5]	1.2 [1.5 ÷ 3.1]
	Ant/post	*Med/lat*	*Prox/dist*	*Ant/post*	*Med/lat*	*Prox/dist*
Position [mm]	1.6 [1.6 ÷ 4.3]	0.8 [0.7 ÷ 2.2]	0.8 [1.2 ÷ 1.9]	0.2 [0.0 ÷ 0.8]	0.4 [0.2 ÷ 2.0]	0.6 [0.8 ÷ 1.5]

Over the four patients, the mean of the std devs and the range [minimum ÷ maximum values] of the maximum errors over the three repetitions are reported for each of the discrepancy variables (three positions and three orientations) for both the femur and tibia.

Table 2. Discrepancy in Position

	Femur						Tibia					
	(+) *Ant*	*Post* (−)	(+) *Med*	*Lat* (−)	(+) *Prox*	*Dist* (−)	(+) *Ant*	*Post* (−)	(+) *Med*	*Lat* (−)	(+) *Prox*	*Dist* (−)
Group A												
Discrepancies	1.9 ± 1.2 [$0.2 \div 4.2$]		2.1 ± 1.4 [$0.1 \div 5.6$]		3.1 ± 1.3 [$0.9 \div 5.9$]		2.6 ± 1.7 [$0.2 \div 5.7$]		1.9 ± 1.4 [$0.3 \div 5.2$]		2.2 ± 1.8 [$0.0 \div 4.8$]	
Occurrences, no. of patients	13	10	19	4	16	7	4	18	10	12	12	10
Mean of occurrences	2.2	−1.5	2.0	−2.3	3.1	−3.2	2.0	−2.8	1.9	−2.0	1.9	−2.6
Group B												
Discrepancies	1.8 ± 1.4 [$0.3 \div 4.6$]		1.9 ± 1.3 [$0.0 \div 4.5$]		2.9 ± 1.4 [$0.3 \div 5.3$]		1.1 ± 0.5 [$0.3 \div 2.3$]		1.1 ± 0.7 [$0.0 \div 2.8$]		2.1 ± 1.4 [$0.0 \div 5.1$]	
Occurrences, no. of patients	12	9	9	12	8	13	11	10	10	11	13	8
Mean of occurrences	2.0	−1.6	1.3	−2.2	2.6	−3.2	1.2	−1.1	1.0	−1.2	2.5	−1.4

Mean ± std dev and [minimum ÷ maximum] values for the final versus planned pose discrepancy. For each of the three position axes, the occurrences (number of patients) in one and in the other direction are reported, together with the relevant means for the femur (left) and tibia (right) and for group A (top) and B (bottom).

intervention is still critically necessary, including sharing the same 6 degrees of freedom between the two. Besides the traditional shape-matching procedure, the use of standard CAD models of the components for each patient does not account for the possible critical mismatch between the geometry of the CAD models and that of the final components, the latter resulting from complex manufacturing, in part performed and refined manually. The complexity of these sources resulted in a difficult design of a possible thorough validation test for the present measurements. The overall accuracy of the our 3D matching procedure, that is, the pseudo-biplane imaging technique, was assessed by looking only at the components, which provided encouraging results. However, this would represent the accuracy of the implant-to-implant pose measurement, not of the implant-to-bone that we investigated, which remains unknown.

The cement mantle also affects the final component positioning[4,24]; this may have played a role in a few observed differences, though we assume that this effect is similar for the two PSI systems. However, the final overall consistency between preoperative plans and final alignments was investigated, which includes cement in real TKR. Finally, the present results come from a small number of patients, although the number compares with that of other fluoroscopic clinical analyses.[25,26] In addition, our main aim was not to find significant differences between the PSI systems, though these are reported and discussed.

The present innovative technique for analyzing 3D final location of TKR components after PSI-based treatments is an evolution of a standard procedure[19] based on an iterative 2D to 3D spatial matching from routine medical images and applied largely for kinematics analyses at the replaced knees by looking at the implanted components.[25,26] For the overall PSI procedures, CAD models of the patient's bones were available from CT or MRI scans, and the spatial matching was also extended to these, thus obtaining all 6 degrees of freedom for relative component-to-bone location. This condition saved the patients in the present study from additional post-operative CT scans and complex analyses, such as those used previously for analyzing final component locations for transverse plane alignments[12] or joint lines restoration.[27]

Overall, satisfactory results in terms of position and orientation between the preoperative plan and the corresponding final implantation were found, with an absolute discrepancy of <3.1 mm and 1.9°, respectively. Comparison with the literature of the present implant positions and orientations is restricted to a few previous similar studies.[14,16,27–29] This is due to the originality of the present estimation technique, but mainly because most of the previous study aims were the final versus plan consistency of the component-to-limb alignments, rather than the present separate component-to-bone poses at the femur and tibia. Nevertheless, a few considerations can be made. As for

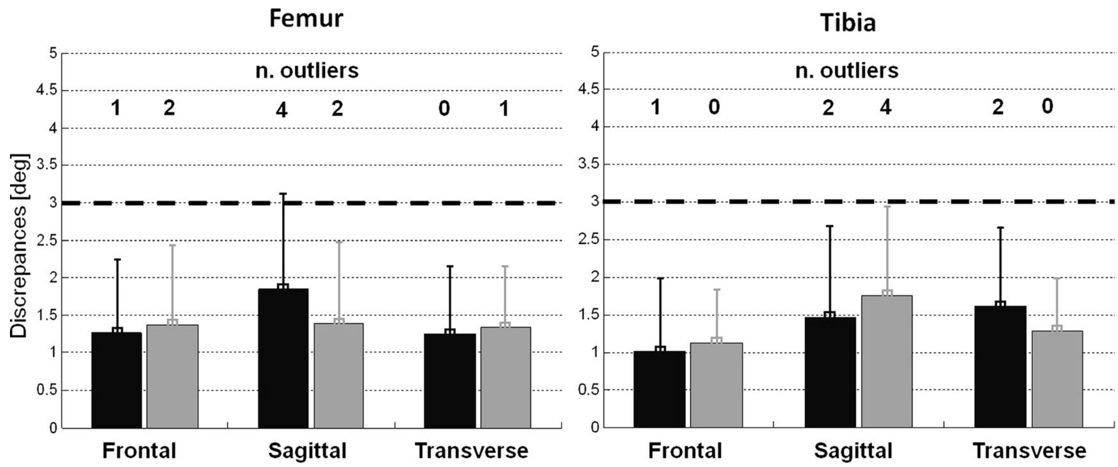

Figure 2. Box plots for the mean and std dev of the absolute values of the discrepancy in orientation for group A (black) and B (gray) and for the femur (left) and tibia (right). For each variable, the number of outliers, those >3°, are also indicated.

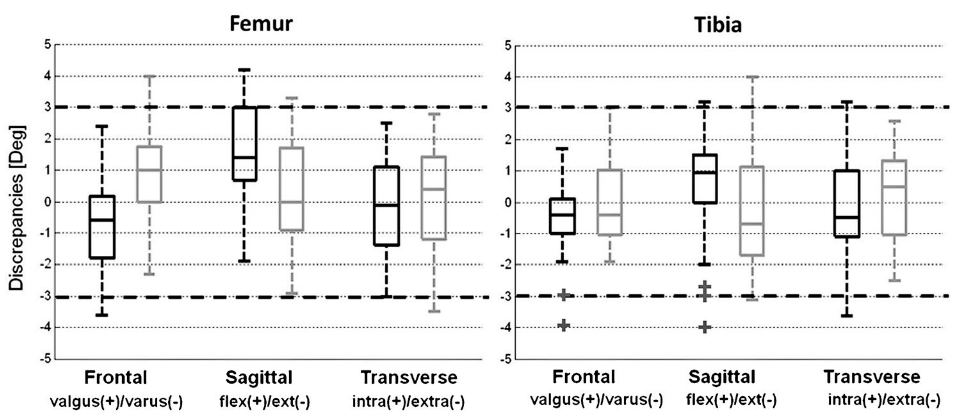

Figure 3. Box plots for the mean and std dev of the relative values (with the original sign) of the discrepancy in orientation for group A (black) and B (gray) and for the femur (left) and tibia (right). In each plot, the boxes indentify the lower, median, and upper quartile values; the whisker lines extending from each end of the box show the extent of the rest of the data; statistical-based outliers are also shown (crosses).

the positions, the largest discrepancies in both systems were found in the femoral proximo-distal direction, which implies important variations of the joint line.[27,29] For the orientations, the highest percentage of outliers, ~20%, was in the sagittal planes (Fig. 2), 4 out of 23 at the femur (group A) and 4 out of 21 at the tibia (group B). However, these are less than those of a previous study,[28] and in any case the misalignment in the sagittal plane is considered the least critical factor for final TKR outcome.[4] In the coronal plane, these outliers are even less, ~10% in the worst case. This percentage compares well with those obtained over a much larger cohort of patients,[14] particularly for the tibial component. In the transverse plane, the present discrepancy in orientation was a little larger than that previously reported.[30]

Recently, several papers reported differences between PSI systems and conventional instrumentation,[14,16,31] but ours is the first comparative analysis between two different PSI systems, one CT and the other MRI/X-ray based. The comparison revealed a significantly larger discrepancy for the tibial A/P and M/L positions in group A. This was somehow expected because the tibial cutting guide only of group B is designed to control fully the bone preparation in 3D for hosting the tibial base plate. This might be associated with the corresponding imaging system for which the cartilage is also considered. Instead, the proximal–distal position is controlled in both systems, and for this there were no significant differences. As for the orientations, the comparison did not reveal significant differences. A little larger mean value for the sagittal discrepancy at the femur was observed in group A compared with group B, the opposite at the tibia. In the transverse plane, a little larger discrepancy and number of outliers were found in group A compared with group B at the tibia; however, despite the relevant smaller control in the former, these differences were not significant. Where the distinct directions over the three axes were meant for comparison

Table 3. Discrepancy in Orientation

	Femur						Tibia					
	Valgus (+)	*Varus* (−)	*Flex* (+)	*Ext* (−)	*Intra* (+)	*Extra* (−)	*Valgus* (+)	*Varus* (−)	*Flex* (+)	*Ext* (−)	*Intra* (+)	*Extra* (−)
Group A												
Occurrences, no. of patients	9	14	20	3	10	13	10	12	17	5	9	13
Mean of occurrences	1.0	−1.4	1.9	−1.0	1.4	−1.2	0.6	−1.3	1.2	−2.4	1.8	−1.4
Group B												
Occurrences, no. of patients	16	5	11	10	11	10	8	13	10	11	12	9
Mean of occurrences	1.4	−1.1	1.6	−1.2	1.3	−1.4	1.4	−1.0	1.7	−1.8	1.2	−1.4

Mean ± std dev and [minimum ÷ maximum] values for the final versus planned pose discrepancy. For each of the three position axes, the occurrences (number of patients) in one and in the other direction are reported, together with the relevant means for the femur (left) and tibia (right) and for group A (top) and B (bottom).

between the two PSI systems, a significant bias in varus and flexion was found for the femur in group A, although this does not show a particular advantage for any of the two systems.

In conclusion, we have reported final positions and orientations of TKR components with respect to the corresponding bone, and relevant discrepancies from the preoperative plan have been discussed. For the first time, this was fully in 3D, with a much less invasive technique, from routine fluoroscopic images, and for two different available PSI systems. The repeatability test revealed the reliability of the present analysis, both for the femur and tibia. Although we observed a number of outliers for the component orientations on all three anatomical planes, our results support an overall consistency between preoperative plans and final surgical results for the two PSI systems. Our results also highlight a number of possible system-specific issues, knowing which the surgeon can pay more attention to a number of relevant surgical actions.

REFERENCES

1. Bäthis H, Shafizadeh S, Paffrath T, et al. 2006. Are computer assisted total knee replacements more accurately placed? A meta-analysis of comparative studies. Orthopade 35:1056–1065.
2. Cheng T, Zhao S, Peng X, et al. 2012. Does computer-assisted surgery improve postoperative leg alignment and implant positioning following total knee arthroplasty? A meta-analysis of randomized controlled trials? Knee Surg Sports Traumatol Arthrosc 20:1307–1322.
3. Ensini A, Catani F, Leardini A, et al. 2007. Alignments and clinical results in conventional and navigated total knee arthroplasty. Clin Orthop Relat Res 457:156–162.
4. Catani F, Biasca N, Ensini A, et al. 2008. Alignment deviation between bone resection and final implant positioning in computer-navigated total knee arthroplasty. J Bone Joint Surg Am 90:765–771.
5. Sparman M, Wolke B, Czupalla H, et al. 2003. Positioning of total knee arthroplasty with and without navigation support. A prospective, randomised study. J Bone Joint Surg Br 85:830–835.
6. Mason JB, Fehring TK, Estok R, et al. 2007. Meta-analysis of alignment outcomes in computer-assisted total knee arthroplasty surgery. J Arthroplasty 22:1097–1106.
7. Lombardi AV Jr, Berend KR, Ng VY. 2011. Neutral mechanical alignment: a requirement for successful TKA: affirms. Orthopedics 34:504–506.
8. Sikorski JM. 2008. Alignment in total knee replacement. J Bone Joint Surg Br 90:1121–1127.
9. Willcox NM, Clarke JV, Smith BR, et al. 2012. A comparison of radiological and computer navigation measurements of lower limb coronal alignment before and after total knee replacement. J Bone Joint Surg Br 94:1234–1240.
10. Yaffe MA, Koo SS, Stulberg SD. 2008. Radiographic and navigation measurements of TKA limb alignment do not correlate. Clin Orthop Relat Res 466:2736–2744.
11. Berhouet J, Beaufils P, Boisrenoult P, et al. 2011. Rotational positioning of the tibial tray in total knee arthroplasty: a CT evaluation. Orthop Traumatol Surg Res 97:699–704.
12. Chauhan SK, Clark GW, Lloyd S, et al. 2004. Computer-assisted total knee replacement. A controlled cadaver study

using a multi-parameter quantitative CT assessment of alignment (the Perth CT Protocol). J Bone Joint Surg Br 86:818–823.
13. Conteduca F, Iorio R, Mazza D, et al. 2012. Are MRI-based, patient matched cutting jigs as accurate as the tibial guides? Int Orthop 36:1589–1593.
14. Ng VY, DeClaire JH, Berend KR, et al. 2012. Improved accuracy of alignment with patient-specific positioning guides compared with manual instrumentation in TKA. Clin Orthop Relat Res 470:99–107.
15. Noble JW Jr, Moore CA, Liu N. 2012. The value of patient-matched instrumentation in total knee arthroplasty. J Arthroplasty 27:153–155.
16. Nunley RM, Ellison BS, Zhu J, et al. 2012. Do patient-specific guides improve coronal alignment in total knee arthroplasty? Clin Orthop Relat Res 470:895–902.
17. Spencer BA, Mont MA, McGrath MS, et al. 2009. Initial experience with custom-fit total knee replacement: intra-operative events and long-leg coronal alignment. Int Orthop 33:1571–1575.
18. Stronach BM, Pelt CE, Erickson J, et al. 2013. Patient-specific total knee arthroplasty required frequent surgeon-directed changes. Clin Orthop Relat Res 471:169–174.
19. Banks SA, Hodge WA. 1996. Accurate measurement of three-dimensional knee replacement kinematics using single- plane fluoroscopy. IEEE Trans Biomed Eng 43:638–649.
20. Fantozzi S, Catani F, Ensini A, et al. 2006. Femoral rollback of cruciate-retaining and posterior-stabilized total knee replacements: in vivo fluoroscopic analysis during activities of daily living. J Orthop Res 24:2222–2229.
21. Zuffi S, Leardini A, Catani F, et al. 1999. A model-based method for the reconstruction of total knee replacement kinematics. IEEE Trans Med Imaging 18:981–991.
22. Grood ES, Suntay WJ. 1983. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng 105:136–144.
23. Jeffery RS, Morris RW, Denham RA. 1991. Coronal alignment after total knee replacement. J Bone Joint Surg Br 73:709–714.
24. Dunbar NJ, Roche MW, Park BH, et al. 2012. Accuracy of dynamic tactile-guided unicompartmental knee arthroplasty. J Arthroplasty 27:803–808.
25. Leszko F, Hovinga KR, Lerner AL, et al. 2011. In vivo normal knee kinematics: is ethnicity or gender an influencing factor? Clin Orthop Relat Res 469:95–106. doi: 10.1007/s11999-010-1517-z
26. Catani F, Belvedere C, Ensini A, et al. 2011. In-vivo knee kinematics in rotationally unconstrained total knee arthroplasty. J Orthop Res 29:1484–1490.
27. Sato T, Koga Y, Sobue T, et al. 2007. Quantitative 3-dimensional analysis of preoperative and postoperative joint lines in total knee arthroplasty: a new concept for evaluation of component alignment. J Arthroplasty 22:560–568.
28. Boonen B, Schotanus MG, Kort NP. 2012. Preliminary experience with the patient-specific templating total knee arthroplasty. Acta Orthop 83:387–393.
29. Ensini A, Catani F, Biasca N, et al. 2012. Joint line is well restored when navigation surgery is performed for total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 20:495–502.
30. Heyse TJ, Tibesku CO. 2012. Improved femoral component rotation in TKA using patient-specific instrumentation. Knee Nov 7. [Epub ahead of print]. pii: S0968-0160(12)00198-6. doi: 10.1016/j.knee.2012.10.009
31. Bali K, Walker P, Bruce W. 2012. Custom-fit total knee arthroplasty: our initial experience in 32 knees. J Arthroplasty 27:1149–1154.